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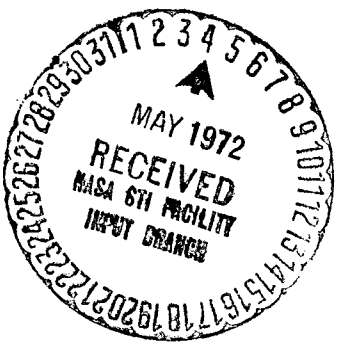

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322 DAYS IN THE SEA OF RAINS

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The lunar studies being carried out in our country provide for the thorough study of that celestial body over extensive areas. The world's first mobile laboratory, the "Lunokhod-1," was created for this purpose and was delivered to the surface of our natural satellite in the region of the Sea of Rains. It operated continuously for a period of 10½ months (17 November 1970 - 4 October 1971).

The following data are indicative of the scope of the performed work. During the period of "Lunokhod-1" operation there were a total of 171 communications contacts; a total of 24,829 commands were transmitted through radio channels; a chemical analysis of lunar ground was made over a period of 39 hours 16 minutes at 25 points on the lunar surface. The duration of operation of the astrophysical instruments, the X-ray telescope and radiometric apparatus, was more than 3½ months. By means of radiotelevision systems the lunokhod transmitted to earth 206 panoramas and more than 20,000 photographs of the lunar surface. The physical and mechanical properties of the surface layer of the ground (regolith) were studied at more than 500 points within craters of different morphological classes and on their slopes, on untrodden lowland areas, and on the ground compacted by the lunokhod. And although the movement of the wheeled vehicle over the trackless lunar wastes was not the primary objective of this experiment so unprecedented in duration and complexity in the history of cosmonautics, the lunomobile covered a distance of 10,540 meters, making possible a detailed study of the topography and morphology of the lunar surface over an area of 80,000 m^2. The Chief Designer has stated that if the lunokhod had been assigned but the single mission of movement the distance which it covered would have been many tens of kilometers.

During the third lunar day (January 1971) an interesting navigation problem was solved: arrival at a stipulated point on the lunar surface. The lunokhod returned to the landing site, which in this case was used as a control point for evaluating the quality of the experiment.

The drivers, remaining on earth, guided the mobile laboratory equipped with different kinds of scientific instrumentation and at their discretion selected the route on the lunar surface.

The results of prolonged operation of the lunar mobile laboratory enable scientists, designers and specialists to determine the position of this unique vehicle in investigation of the lunar surface and to compare its capabilities with other Soviet and foreign space vehicles. The "Lunokhod-1" differs from the Soviet and American automatic vehicles preceding it in a number of essential ways. We will mention the most important of them.

Whereas the "Luna" and Surveyor automatic stations which earlier made a landing on the moon conducted their investigations at the landing site, the mobile laboratory investigated extensive trajectories and entire regions. It was found that the self-propelled vehicle was much more effective than a fixed station.

Another characteristic of the "Lunokhod-1" was that the numerous investigations which it made were of a complex nature. They were not isolated, but supplemented one another. The study of the geomorphological characteristics of any sector, investigation of the carrying capacity of the ground in this same sector at its different points, and chemical analysis of the upper layer, all these interrelated experiments were conducted simultaneously. As a result, it was possible to tie into the relief data on the ground collected within different craters and on their slopes and walls, as well as for the sectors separating the craters.

One should note the interesting fact that the onset of solar flares, especially on 10 December 1970, was precisely registered by the instrument...for studying the chemical composition of the lunar ground: at this time the detectors registered bursts of secondary X-radiation from the ground. These bursts were caused by powerful primary X-irradiation of solar origin. A further study of the charged particles ejected by the sun was made using radiometric instruments.

The next peculiarity of the lunar self-propelled laboratory is its universality. This was the first automatic vehicle so abundantly outfitted with scientific instrumentation. The scientific problems which it solved were not limited to the field of selenology. The prototype of lunar "automobile construction" also laid the beginning for astrophysical observations from the moon, a stable natural platform in space. The lunokhod constantly "observed" X-radiations, measured different characteristics of the fluxes of solar and galactic cosmic rays. Since on the moon there is a considerable lengthening of the time for continuous tracking of the same object and since such factors as the circumterrestrial radiation belts exert no influence on the results of the research, there is full basis for asserting that following high-altitude rockets and artificial earth satellites the mobile lunar laboratory has opened up a new stage in the development of exoatmospheric astronomy.

Still another characteristic of the lunokhod is the flexibility of its scientific program. At the discretion of the specialists the mobile laboratory changed its trajectory of movement, heading for relief features of interest from the scientific point of view: piles of rocks, central peaks within craters, craterlets. Moreover, surveys of the same regions were made from different vantage points. Some experiments were intentionally repeated. Depending on the specific results of geological and astrophysical investigations, the duration of different experiments was changed by commands from the earth.

Finally, still another peculiarity of the mobile laboratory on the moon was the unprecedented lifetime for a lunar vehicle. The first lunokhod not only completely implemented the research program, but also supplied scientists and engineers with a quantity of scientific and engineering data such as they had not obtained from any other automatic station. While on the moon the self-propelled vehicle carried out several "day-night," working cycles, transmitting to earth exceptionally valuable information concerning the running qualities of the chassis, performance of the moving units of the solar cell and pencil-beam antenna, conical-bladed penetrator, television cameras and other systems. Not one of the specialists who planned the experiments and guided their implementation from the earth could complain of a time shortage during the experiments.

These characteristics of the "Lunokhod-1" as a highly effective automatic space vehicle made it possible to obtain many qualitatively new engineering-technical and scientific results in the field of study and use of the moon. Analysis of this unique information is still continuing. Much has already

been done, considered and summarized, although much yet remains to be done. Work is now proceeding on study of the collected experience in guiding the exoplanetary vehicle, making preparations for completing the compilation of a topographic map, ascertaining the dependence between changes in the concentration of chemical elements in the ground and the characteristics of lunar relief, processing statistical data on the parameters and periods of solar flares, and interpreting X-ray photographs of distant energy sources.

The "Lunokhod-1" has now frozen at its perpetual stopping place. But as before it will serve science. Periodically it will be reached by a pencil-beam laser ray and the French reflector mounted aboard it will instantaneously return the signal to earth. As a result, scientists will make extremely precise measurements of the constantly changing distance between the earth and the moon and also investigate the moon's characteristic rotation or libration.

What then are the principal, although not necessarily final, results of operation of the automatic lunar worker?

The prolonged operation of the "Lunokhod-1" made it possible to test many engineering solutions whose effectiveness rested primarily on the faultless operation of all the onboard systems of the vehicle and their components. For example, if one visualizes a machine consisting of 120 elements, on each of which the successful operation of the entire vehicle is dependent, such computations can be made. We will assume that each such element is so faultless in operation that it will malfunction but once in a hundred cases. Then the reliability of the entire vehicle will be such that of three similar vehicles only one will be able to operate successfully. Indeed, prior to the "Lunokhod-1" no other mobile vehicles had been tested on the moon. It was the first and more complex than the so-called hypothetical vehicle. That is why the highly reliable operation of the world's first lunokhod represents not only an outstanding accomplishment of engineering and design thought, but also an enormous success of science, whose interests in our time are closely intertwined with the needs of practical life, and especially with cosmonautics.

During the first months of lunokhod operation much time was devoted to checking its overall performance and cross-country characteristics. Later more and more attention was given to scientific experiments. One of the most important missions was a topographic study of the terrain. This was for an especially important practical purpose: evaluating the relief and orientation in the relief for ensuring vehicular

passability and the selection of a direction for safe movement during the implementation of scientific experiments.

The landscape along the "Lunokhod-1" trajectory of movement was characterized by uniformity and absence of characteristic landmarks. As indicated by topographic investigations, in the region of landing of the "Luna-17" station there were no obstacles which could not be overcome or avoided.

The geometric characteristics of many craters were determined not only from photopanoramas, but also from changes in the longitudinal and transverse tilts of the lunokhod chassis. These data were continuously transmitted through radiotelemetric channels. The discrepancies between the results obtained in the two different methods did not exceed 12%. Table 1 gives the statistical distribution of craters by sizes in the region of the lunokhod exploratory runs.

The panoramas show the craters which have undergone different stages of destruction over the course of millions and billions of years. Fresh craters have clearly defined rims and the steepness of the upper part of their inner slopes attains 40°. The older craters are characterized by blurred outlines without a clearly expressed wall and the greatest steepness of their inner walls is less than 20°. Selenologists have concluded that the explored region with respect to its regolith and the occurrence of craters and rocks is close to the earlier studied marias in the lunar equatorial zone.

The wheel tracks of the lunokhod visible on the panoramas, as well as the results obtained using the conical-bladed penetrator, made it possible to determine the mechanical properties of the ground along the entire trajectory of movement. These properties were extremely unstable from point to point. The carrying capacity of the ground varied from 0.2 to 1.0 kg/cm^2 and volumetric weight varied in the range 1.5 to 1.7 g/cm^3. The lunar ground could be compacted without particular difficulty. The punch penetrated most readily into the ground on the walls of craters and with the greatest difficulty in sectors covered with small stones. The specialists drew the fundamental conclusion that the traction-cohesion characteristics of the self-propelled chassis were entirely adequate for reliable movement of the lunokhod along the surface.

Data from the RIFMA spectrometric apparatus, designed for making a chemical analysis of the lunar ground, confirmed the general idea of the origin of the upper layer forming as a result of fragmentation for the most part of basaltic

rocks. Table 2 gives the results of a chemical analysis of the fine ground fraction in different regions of the moon.

With completion of "Lúnokhod-1" operation X-ray astronomy can mark its third birth. Astrophysics marked its first birthday 25 years ago when instruments carried aboard high-altitude rockets for the first time registered X-radiation from an extraterrestrial source, the solar corona heated to a million degrees. Later scientists acquired still more powerful means for making X-ray observations: artificial earth satellites.

But truly unlimited possibilities are opening up before X-ray astronomy by the use of detectors placed on the moon. Scientists were convinced of this in the course of operating the X-ray telescope on the "Lunokhod-1" during its stops between communication contacts. Since the "angle of view" of this telescope was about 3.5° and the angular velocity of lunar rotation was not much more than 0.5° per hour, exposure to the radiation of the same source during registry lasted more than six hours. This is 10 times greater than the duration of the exposures possible, for example, when using artificial earth satellites in low orbits. As a result, it is possible to observe faint sources of X-rays, situated at enormous distances, usually located outside the galactic plane, and also relatively strong extragalactic sources. In addition to discrete sources, it was possible to register the diffuse X-ray background. As might be expected, the contribution of the Galaxy to the diffuse background was extremely small. Its intensity was uniform in all directions (isotropic). The rays emanate from the entire sky, which is attributable to the extragalactic origin of the background. The position of the discrete sources in the heavens was computed using data on the observation times, coordinates of the lunokhod and the tilts of its characteristic axes relative to the local vertical.

The program of astrophysical observations included investigation of low-energy cosmic (solar and galactic) rays. The radiometer carried aboard the lunokhod had a set (six) of semiconductor detectors and two gas-discharge Geiger counters. During lunokhod operation regular measurements were made of the fluxes and angular distribution of protons with an energy of 1-5 MeV and alpha particles with an energy 4.5-8.5 MeV, the intensity of electrons with an energy 0.05-2 MeV was estimated, and protons and electrons with energies greater than 30 MeV and greater than 2 MeV respectively were registered.

Already during the first months of radiometer functioning on the moon it was possible to register intensive chromospheric flares on the sun. The series of flares on 10 and 11

December 1970 was particularly powerful. The times of the flares were registered not only by ground stations, but as already mentioned, by the RIFMA roentgenospectrometric instrument. After two days all the detectors of the radiometric apparatus registered an intensity maximum of protons with an energy of 1-5 MeV. The height of the peak exceeded the background level by almost a factor of 10,000. At the same time, this led to a decrease in the intensity of galactic cosmic rays. The plasma ejected at the time of the solar flares, like a wind, blew away the arrivals from the Galaxy, not allowing them to reach the moon and our planet. The sun "boiled," causing magnetic storms on the earth. It is interesting to note that this increase in the intensity of solar rays and decrease in galactic rays was also observed aboard the "Venera-7" interplanetary station, at that time situated at a distance of about 60 million kilometers from the "Lunokhod-1." The sun was observed simultaneously from ground stations and from aboard artificial earth satellites.

Table 1

Диаметры кратеров, м 1	Количество кратеров на площади 100 × 100 м 2
3—10	15
10—30	5
30—100	1,2
100—300	0,3
300—1000	0,06

1) Diameter of craters, m; 2) Number of craters in an area 100 x 100 m

Table 2

Элемент 1	Море Спокойствия 2 / Аполлон-11 8	Центральный Залив 3 / Сервейор-6 9	Океан Бурь 4 / Аполлон-12 8	Кратер Тихо 5 / Сервейор-7 9	Море Изобилия 6 / Луна-16 10	Море Дождей 7 / Луноход-1 11
Si	20	23	20	21	20	20
Fe	12	10	13	4	13	12
Ca	8	9	7	13	9	8
Al	6	8	7	11	8	7
Mg	5	4	7	4	5	7
Ti	5	2	2	0,4	2	4
K	0,1	—	0,3	—	0,08	1
Na	0,4	0,6	0,3	0,5	0,3	—

1) Element; 2) Sea of Tranquillity; 3) Central Gulf; 4) Ocean of Storms; 5) Tycho Crater; 6) Sea of Fertility; 7) Sea of Rains; 8) Apollo; 9) Surveyor; 10) Luna; 11) Lunokhod-1

In June 1971 the "Lunokhod-1" detectors repeatedly measured cosmic radiation in different energy ranges. The results agreed well with similar experiments carried out using the "Mars-2" and "Mars-3" automatic stations. Thus, practical confirmation was obtained of the high effectiveness in using space vehicle systems for studying radiation conditions in interplanetary space and in the earth's neighborhood. In the future this method will evidently find very broad application.

The "Lunokhod-1" is an automatic vehicle which not only explored the moon, but also laid a foundation for the moon's use (for the time being only in the interests of one field of human activity -- astrophysics). In the future we will become witnesses of the operation of real lunar observatories. But the problems involved in using the earth's natural satellite are not naturally thereby exhausted. It is difficult to exaggerate the results which scientists will obtain using lunar stations designed for long-term biological investigations. It is also not impossible that the lunar expanses will one day be used for conducting different experiments and tests in the fields of power production, engineering and materials science.